LETTERS TO THE EDITOR

ASTRONOMY

Microwave Background in a Steady-state Universe

It has been widely claimed that the background microwave radiation observed by Penzias and Wilson[1] and Roll and Wilkinson[2] must originate from a radiation dominant, early phase of the Universe. Hoyle and Wickramasinghe[3] have, however, discussed the possibility of a more local origin for this radiation. They point out that the energy density arising from the conversion of hydrogen to helium in all galaxies is about 10^{-13} erg/cm^3, close to the energy density of the 3° K blackbody field. If an appreciable fraction of this energy could be thermalized by dust grains the observed "black body" microwave spectrum might be explained. The requirement is that quantum oscillators covering much of the frequency range 0·01 cm^{-1} to 10 cm^{-1} are present in the grains. While arguments may be given for the presence of localized oscillation modes within this frequency range, the strongest evidence at the present time would seem to be for the existence of oscillators close to about 10 cm^{-1} (Sievers[4], Sievers and Takeno[5]). Such frequencies may be appropriate for the oscillation of weakly bound substitutional impurities in crystals. In a typical case the oscillator strength could be about 0·1 and the line width about 1/10 of the central frequency[4]. We shall consider here the effect of a few strong emission bands at about 1 to 10 cm^{-1} which may be present in grains. From a total of about 10^{55} grains in the Galaxy each containing approximately 10^5 impurity oscillators we could obtain an infra-red emission at about 10 cm^{-1} equal to approximately 1/3 of the entire luminosity of the Galaxy. This flux of Galactic radiation at $\nu \sim 10$ cm^{-1} (1 mm wavelength) could produce the observed excitation of the $J=1$ rotational levels of cyanogen (CN) (Field and Hitchcock[6]), but it would not account for the microwave observations[1,2].

We shall consider the consequences of a similar process operating in other galaxies. It does not seem likely that dust is a phenomenon in any way peculiar to our own galaxy. There is evidence of interstellar polarization in *M*31 and of interstellar reddening in *SMC* and *LMC* as well as of conspicuous striations in many extragalactic objects—all of which point to the presence of dust[7]. If dust is present, it is also reasonable to find effects arising from impurity atoms in the grains.

For a steady-state model of the Universe we shall assume that in every element of proper volume an appreciable fraction of the galaxies contains interstellar dust which can efficiently absorb starlight and re-emit about 30 per cent of the total luminosity of the galaxy through impurity induced resonances at about 10 cm^{-1}. Quanta emitted from a galaxy at $\nu \approx 10$ cm^{-1} will be red-shifted to $\lambda = 7{\cdot}35$ cm and 3·2 cm at red-shifts $z \approx 73$ and 31, respectively. While galaxies can also absorb radiation at $\nu \approx 10$ cm^{-1}, the mean free path of an emitted quantum between galaxies is large, about 10^4 mparsec. This corresponds to a red-shift $z \simeq 3$; thus a quantum with original frequency $\nu = 10$ cm^{-1} would be red-shifted well outside the width of the absorption band when it encounters another galaxy.

Let N denote the number of galaxies per unit proper volume in the universe. Then the number of galaxies observed at present with red-shifts between z and $z+\mathrm{d}z$ is given by

$$\mathrm{d}n = 4\pi\left(\frac{c}{H}\right)^3 N \frac{z^2}{(1+z)^3}\,\mathrm{d}z \tag{1}$$

where H is the Hubble constant and c the velocity of light. We shall assume that a fraction α of these galaxies contains interstellar dust and takes part in the thermalization process described. Suppose the amount of radiation emitted per unit time by a typical galaxy in this manner is L, and that this radiation has a normalized spectral function I (ν), that is,

$$\int_0^\infty I(\nu)\mathrm{d}\nu = 1 \tag{2}$$

Because of the expansion of the universe, the observed normalized spectral function from a galaxy of red-shift z is

$$I(z,\nu) = (1+z)I(\nu.\overline{1+z}) \tag{3}$$

The observed radiation flux per unit time per unit frequency range from a galaxy of red-shift z is therefore given by

$$\begin{aligned} S(z,\nu) &= \frac{LH^2}{4\pi c^2 z^2(1+z)^2}\,I(z,\nu) \\ &= \frac{LH^2}{4\pi c^2 z^2(1+z)}\,I(v.1+z) \end{aligned} \tag{4}$$

Adding contributions from all galaxies in the universe we get

$$\alpha \int S(z,\nu)\mathrm{d}n = \alpha\left(\frac{c}{H}\right)LN \int_0^\infty \frac{I(\nu.\overline{1+z})\mathrm{d}z}{(1+z)^4} = \mathscr{J}(\nu) \tag{5}$$

$\mathscr{J}(\nu)$ dν denotes the total radiation crossing unit area per unit time in the frequency range dν.

We shall first consider the simple case in which the thermalization mechanism in the interstellar dust of each galaxy results in the radiation of a sharp line of frequency ν_0. This corresponds to

$$I(\nu) = \delta(\nu - \nu_0) \tag{6}$$

From equation (5) we get

$$(\nu) = \begin{cases} \alpha\left(\dfrac{c}{H}\right) LN \dfrac{\nu^3}{\nu_0{}^4}, & \nu \leqslant \nu_0 \\ 0, & \nu > \nu_0 \end{cases} \tag{7}$$

Thus although each galaxy emits a sharp line, the net contribution from all galaxies results in a continuum spectrum given by equation (7). It is of interest to note that the spectrum continues only on the long wavelength side of the line emitted by a typical galaxy.

Because a general function can be represented as a superposition of suitably weighted delta functions, we can consider the more complicated forms of $I(\nu)$ by superposing functions of the form in equation (7). The crystallographic properties of interstellar grains are yet to be fully investigated for us to give a precise form for $I(\nu)$ against ln ν. The curve will have a slope of three at the very long wavelengths ($\nu \to 0$). As the range of ν overlaps that of $I(\nu)$, however, the slope will be reduced.

The case where $I(\nu)$ consists of two sharp lines at the original frequencies ν_1, ν_2 is shown schematically in Fig. 1. We envisage a situation where $\nu_2 \approx 1$–10 cm^{-1} and $\nu_1 \approx 0{\cdot}2$ cm^{-1}, the latter frequency lying between the observations of Penzias and Wilson[1] and of Roll and Wilkinson[2]. There is crystallographic evidence for the presence of impurity oscillators around both such frequencies—the former arising from bodily oscillations of a weakly bound impurity atom, and the latter due to hindered rotations of a diatomic molecule in a crystal[8,9]. The width of the lines is not relevant because we do not require a coverage by individual lines. It is clear from Fig. 1 that two suitably placed emission lines may give rise to a microwave continuum with a slope of about 2 between $\lambda = 7{\cdot}35$ cm and $\lambda = 3{\cdot}2$ cm, in accord with the observations.

It remains to determine the magnitude of the flux arising from our model. From equation (7) the flux arising from a line at $\nu_0 \approx 10$ cm^{-1} is $\sim 10^{-31}$ erg/cm^3 (c/s)$^{-1}$ at $\lambda \approx 7{\cdot}35$ cm, assuming $\alpha \approx 1$, $L \approx 10^{43}$ erg/sterad, $N \approx 1$ mparsec^{-3}, $H^{-1} \approx 10^{10}$ yr. With $\nu_0 \approx 1$ cm^{-1} (refs. 8 and 9), and the same values for the other parameters, we get a flux of about 10^{-27} erg cm^{-3} (c/s)$^{-1}$ at $\lambda \approx 7{\cdot}35$ cm which is in accord with the observations to within a power of 10.

In the preceding calculation the value of total luminosity of the galaxy of about 10^{43} erg/sterad was assumed. This estimate is based on the observed stellar radiation at visible wavelengths. The energy output of a galaxy in the ultra-violet at $\lambda \leq 2000$ Å is uncertain. In young spiral galaxies it could not be ruled out that the total stellar emission in the ultra-violet exceeds the visible output by a factor 10–100. Dust grains present in such galaxies would absorb this radiation with an efficiency factor of about five times greater than for visible light. Thus a galaxy having an optical depth of order unity for visible light will have $\tau \approx 5$ in the ultra-violet. The result is that no ultra-violet radiation can escape from the galaxy. The grains which absorb this energy will re-radiate it in the microwave spectral region in the manner described here. The microwave power of galaxies could thus exceed the visible power by a factor of about 100.

Hoyle and Tayler's[10] estimate of the He/H ratio from the energy output of stars is of interest in this connexion. Taking $L \approx 4 \cdot 10^{43}$ erg/sterad as the optical energy output of all the stars in the galaxy they obtain a He/H ratio of about 0·01, resulting from the conversion H→He throughout the age of the galaxy. The discrepancy between this estimate and the observed value He/H ratio of about 0·1 would be resolved if the total energy output of the galaxy is about 10 times in excess of that deduced from the optical emission alone.

Our final remarks concern the close equality between the energy density of the microwave background and that of several galactic fields (cosmic rays, galactic magnetic field, etc.) which was pointed out by Hoyle and Wickramasinghe[3]. It would be a remarkable coincidence if the primordial radiation from a big bang universe possessed the same energy density as these galactic quantities. The present explanation of the microwave background has the advantage of linking the observed flux with processes currently operating in galaxies.

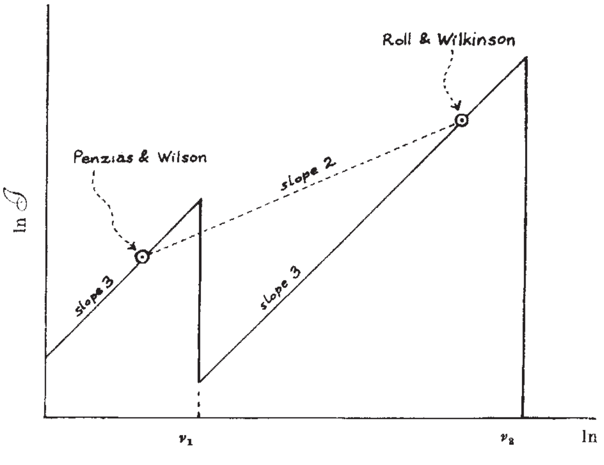

Fig. 1. Schematic representation of a 2-line spectrum with lines at ν_1 and ν_2. The dotted line shows how a slope of 2 may be measured between two observational points.

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Diameters of Some Quasars at a Wavelength of 66·9 cm

THE measurement of the diameter of radio sources in the range of 10^{-2} sec of arc or less has recently been made possible by a new technique in radio interferometry. Independent stable local oscillators are used to convert the signals at the two stations to frequencies which are recorded on magnetic tapes. In principle, these long baseline interferometers (LBI) can operate at any separation.

Measurements at 49 cm wavelength with a baseline of 220 km ($4{\cdot}6 \times 10^5\lambda$) have been reported by the NRAO Arecibo group[1], and at the 18 cm hydroxyl line wavelength with a baseline of 845 km ($4{\cdot}7 \times 10^6\lambda$) by the MIT–NRAO group[2]. Measurement at 66·9 cm wavelength with baselines of 183 km ($2{\cdot}7 \times 10^5\lambda$) and 3,074 km ($4{\cdot}6 \times 10^6\lambda$) have also been reported by the Canadian LBI group[3]. A further series of observations has been made at 66·9 cm with the 3,074 km baseline during the period July 26–29, 1967, in which fringes of amplitude greater than 4 flux units have been detected from eight sources.

Table 1 shows the fringe visibilities determined from both the $2{\cdot}7 \times 10^5\lambda$ baseline (position angle 103°) and the $4{\cdot}6 \times 10^6\lambda$ baseline (position angle 95°). The details of the interferometer have been described previously[4]. Most of the observations were taken near the instrument meridian. The fringe amplitudes were determined from artificial fringes produced by the introduction of coherent c.w. signals at each receiver. The level of these signals was commensurate with the total power output from sources of known flux value, taking into account the bandpass characteristics of the system. The fringe visibilities were then derived from comparison with adopted zero spacing flux values as shown in Table 1. The three highest visibilities at the $4{\cdot}6 \times 10^6\lambda$ spacing and the nine highest visibilities at the $2{\cdot}7 \times 10^5\lambda$ baseline were nearly equal, and close to unity. A slight adjustment was therefore applied in deriving the values in Table 1 so that the average of each of the groups was normalized to unity. The estimated probable errors of the results are included with each entry. The last column lists source diameters computed on the assumption of a Gaussian model. For sources observed at both separations the data from the longer baseline were used. About forty other sources were observed in the July programme. More elaborate data processing will be necessary, however, to determine their visibilities.

At small elongations interplanetary scintillation could cause a significant reduction in fringe amplitudes. At the time of observation, however, the sources closest to the Sun (*CTA* 21, *3C* 273*B*, *3C* 279 and 1127–14) had